

AD A049170

AD No.

DDC FILE COPY

12
B.S.

CHARACTERIZATION OF PASSIVE FILMS USING
INFRARED AND RAMAN SPECTROSCOPY

TECHNICAL REPORT NUMBER 2

CONTRACT NUMBER: N00014-76-c-0889

SUBMITTED TO:

DEPARTMENT OF THE NAVY
OFFICE OF NAVAL RESEARCH
METALLURGY PROGRAM - CODE 471

PREPARED BY:

R. HEIDERSBACH, C. BROWN, R. THIBEAU
AND A. GOLDFARB
DEPARTMENT OF OCEAN ENGINEERING
UNIVERSITY OF RHODE ISLAND
KINGSTON, RHODE ISLAND 02881

JANUARY 1978

DDC
JAN 27 1978
F

CHARACTERIZATION OF PASSIVE FILMS USING
INFRARED AND RAMAN SPECTROSCOPY

TECHNICAL REPORT NUMBER 2

CONTRACT NUMBER: NO0014-76-c-0889

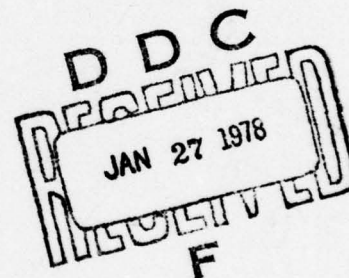
SUBMITTED TO:

DEPARTMENT OF THE NAVY
OFFICE OF NAVAL RESEARCH
METALLURGY PROGRAM - CODE 471

PREPARED BY:

R. HEIDERSBACH, C. BROWN, R. THIBEAU
AND A. GOLDFARB
DEPARTMENT OF OCEAN ENGINEERING
UNIVERSITY OF RHODE ISLAND
KINGSTON, RHODE ISLAND 02881

JANUARY 1978



ACCESSION NO.	✓
NTIS	✓
DDC	✓
UNANNOUNCED	✓
SITE LOCATION	✓
DISTRIBUTION/AVAILABILITY CODES	
SPECIAL	
A	

(14) TA-2

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER Technical report no. 2	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Characterization of Passive Films Using Infra-red and Raman Spectroscopy.		5. TYPE OF REPORT & PERIOD COVERED Annual Technical 1977
7. AUTHOR(s) R./Heidersbach, C./Brown, R./Thibeau A./Goldfarb		6. PERFORMING ORG. REPORT NUMBER
9. PERFORMING ORGANIZATION NAME AND ADDRESS Department of Ocean Engineering University of Rhode Island Kingston, Rhode Island 02881		8. CONTRACT OR GRANT NUMBER(s) N00014-76-F-0889
11. CONTROLLING OFFICE NAME AND ADDRESS Office of Naval Research Department of the Navy Arlington, Virginia 22217		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		12. REPORT DATE Jan 78
		13. NUMBER OF PAGES twenty-five (25)
		15. SECURITY CLASS. (of this report) unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) This document has been approved for public release and sale; its distribution is unlimited.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report) (9) Annual rept. 1 Jan-31 Dec 77		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Passivity; surface chemistry; iron; lead; water; corrosion		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) This report discusses research at the University of Rhode Island using infrared (IR) and Raman spectroscopy as the primary investigative tools to study passive film formation. Equipment adapted for this purpose is described. Results of studies on lead and iron are presented. The results are analyzed by comparison with thermodynamic data. A tentative new version of Pourbaix's potential - pH diagram for lead in nil-chloride aqueous solutions is presented.		

DD FORM 1 JAN 73 1473

EDITION OF 1 NOV 65 IS OBSOLETE

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

407892

Jlu

INTRODUCTION

The purpose of this project is to develop and demonstrate the use of the complementary techniques of infrared (IR) and Raman spectroscopy for studying passive films. These two techniques provide structural information, similar to that provided by X-ray or electron scattering, but have the advantage of not requiring long range atomic order (crystallinity). The information provided tends to be from thinner surface layers, and they have been used in catalysis and other surface studies to identify and analyze monomolecular surface layers (1). Raman spectroscopy can be used for in situ analysis of passive films in aqueous solutions (2,3). Water is a relatively poor Raman scatterer, which allows the in situ analysis. Unfortunately similarly weak Raman scattering effects are to be expected in some metal oxide and hydroxide systems. Fortunately, IR spectroscopy is highly sensitive to these structures so the two techniques used together can reveal information not available by other methods.

The overall goal of this research is to provide information on passive films to include the effects of alloying additions and anions on the corrosion behavior of structural alloys. Primary emphasis is to be placed on ferrous alloys because of their engineering importance.

Efforts during the past year have involved technique (equipment) development, studies of the passivity of lead in aqueous solution, and preliminary efforts to study iron oxides. Each of these efforts is discussed below.

EQUIPMENT

IR Spectroscopy:

Figure 1 is a schematic drawing of the infrared sample arrangement used in this study. It is a standard double beam, multiple specular reflectance setup such as was first described by Hannah (4). Infrared spectroscopy is normally performed in the transmission mode so most published spectra are from transmission, not reflectance, studies (5). Several papers have discussed the optimum incident angle and number of reflections for IR reflection work (6,7), but these conditions must still be experimentally determined for each different sample. Polarization of the incident light, or of the light prior to entering the monochromator, is very important and the optimal polarization setting must also be determined for each sample. The effect of polarization on a spectrum is an indication of the long-range orientation of the surface film. Figure 2 shows two spectra of the same lead oxide film with two different polarizations. The difference in the relative band intensities indicates that the oxide molecules have some order.

The IR light path shown in Figure 1 is not a series of simple reflections. The light is absorbed at each reflection off of the sample (M_3 in Figure 1). Infrared radiation is absorbed by the passive film to some extent and reflected at the film-metal substrate interface. The strength of the absorption depends, among other things, on wavelength and angle of incidence. The spectrum obtained is a combination reflection-absorption spectrum. Unequivocal analysis techniques

for these spectra, which may be markedly different from transmission spectra, are not available. Some of the uncertainty in analysis is removed by proper utilization of the reference sample (M_3' in Figure 1).

Despite the difficulties described above, infrared spectroscopy is the structural analysis tool most sensitive to thin surface layers (1). Some researchers have used conventional IR transmission spectroscopy to analyze surface films (8) but this technique involves mechanical or chemical removal of the film from the metal substrate, and thus is not amenable to truly thin films. A more promising method is the reflection-absorption one we have used. Others have used similar techniques for analysis of corrosion product layers with success (9,10).

Use of powdered substrates to study surface reactions is also possible. These have the advantage of maximizing the surface area exposed to the infrared beam, thus improving the sensitivity of the method. There are, however, serious drawbacks. For infrared transmission work metal powder absorbs light much too strongly and must be dispersed in a nonreactive and relatively transparent matrix (alumina or silica). For reflectance spectra the problem of analyzing diffuse reflection results is much more difficult than for specular reflection. The powder technique has not been used to date at the University of Rhode Island primarily because of the difficulty of defining the electrochemical exposure conditions of a porous sample. The problem of fabricating alloyed powder particles (each individual particle having the same composition) also exists. It is anticipated that initial efforts to fabricate and expose reactive powder samples will be undertaken during 1978.

The multiple specular reflectance technique requires a large, flat sample. Figures 3-6 show the special sample holder fabricated to hold these samples. Metallurgical preparation techniques used in standard electrochemical studies (11) have been found adequate for infrared spectroscopic studies.

Raman Spectroscopy:

Figure 7 is a schematic of the Raman spectrometer used in this investigation. The laser furnishes the intense monochromatic light needed to excite the molecules of the sample.

The sample cell used is shown in Figure 8. It is similar to other electrochemical cells except for the flat bottom and positioning of the sample. The metal sample is tilted to the optimum angle, approximately 20° for most samples, for collecting scattered light in the monochromator while admitting a minimum of reflected light.

This cell is used to obtain in situ Raman spectra of electrode surfaces in controlled electrochemical environments. After the completion of exposure in solution samples are dried and Raman spectra of the surfaces recorded. The dry sample and in-situ spectra have, in all cases, been similar with somewhat greater spectral intensity observed from the dry surface as shown in Figure 9. Replicate samples exposed in a standard electrochemical cell and first analyzed by infrared spectroscopy were also analyzed by the Raman technique. Both IR and Raman spectra were used to identify the surface films. It is to be noted that all films investigated to date have been metal oxides. It is to be expected that differences between in situ and removed-from-environment spectra may be observed when this investigation is extended to systems where water of hydration or adsorbed water is important.

LEAD

Lead was chosen as the metal for initial studies in this investigation because:

1. lead oxides are predicted to be good Raman scatterers (2);
2. the passive films formed on lead in many aqueous environments are thick and can be analyzed by X-ray diffraction to confirm infrared and Raman spectral results; and
3. lead has a number of common valence states, thus a number of different oxides may form on lead surfaces. Some lead oxides exist as two allotropes.

These latter conditions are analogous to those which would be expected for iron, chromium, and iron-chromium alloys where thin, possibly amorphous, passive films would make confirmation by X-ray or electron diffraction impossible.

Figure 10 is a simplified version of the potential - pH diagram published by Pourbaix (12). It was used to select conditions for a series of exposures intended to produce different passive films on lead substrates. The exposures selected and the results are summarized in Table 1. Figures 2 and 11 show IR spectra of lead oxide films formed under different exposure conditions. Figure 12 shows the infrared spectrum of lead exposed in a carbonate buffer. The observed bands can all be ascribed to basic lead carbonate. The PbO_2 on the surface, which was detected by X-ray diffraction, is not detected by either IR or Raman spectroscopy. Similar effects have been reported in infrared spectra of iron exposed in borate buffers (10). Problems of this nature have necessitated careful choice of buffers to avoid interference by buffer species, a problem for any experimental technique.

Infrared absorption spectra of many metal oxides are available (13), but few Raman spectra of oxides have been published. Of the lead oxides, only spectra of the two forms of PbO can be found in the literature (14). It was necessary to record the spectrum of pure Pb_3O_4 shown in Figure 13 in order to use Raman spectroscopy to identify this compound. A typical surface film spectrum is shown in Figure 14 where it is compared with the spectrum of the pure compound.

Figure 15 is a Pourbaix diagram for lead in nil-chloride solutions. The lines have been redrawn from Figure 10 to reflect the latest thermodynamic data available from the National Bureau of Standards. Figure 15 is in closer agreement with the experimental results of this study. Discrepancies between those species predicted in the diagram and those determined experimentally have not been explained by thermodynamics. Scanning electron microscopy investigations to confirm the spectral results are underway.

The effects of anions on the passive films formed on lead are also being investigated. Experimental Pourbaix diagram investigations for chloride-, sulfate-, and carbonate-containing solutions are underway.

IRON

Few published Raman spectra are available for iron oxides. This situation necessitated the synthesis of a series of iron oxides and the recording of their Raman spectra. Figures 16 and 17 show the spectra of allotropes of FeOOH and Fe_2O_3 . Figure 18 shows the Raman spectrum of Fe_3O_4 in a powder sample and the spectrum of the surface of Armco iron exposed to boiling water. Poling has published the infrared spectrum of an Fe_3O_4 film formed under these conditions (15), and the IR spectrum obtained in our investigation confirms his results. Figure 19 is the IR spectrum of an Armco iron surface after air exposure at 220°C . The presence of several metal oxide allotropes is indicated.

Oxide films on iron are substantially thinner than those formed on lead. This makes confirmation of experimental results by X-ray or electron diffraction more difficult. For this reason primary emphasis during recent months has been shifted to studies of lead surfaces. Further studies on iron are underway. It is anticipated that high-temperature exposures of ferrous alloys will provide thick films amenable to X-ray diffraction confirmation of the infrared and Raman spectra obtained. These will be used for comparison with spectra obtained from low-temperature exposures in aqueous solutions.

TABLE 1

LEAD EXPOSURES CONDUCTED IN NIL-CHLORIDE SOLUTIONS

pH*	Potential (Volts SHE)	Time of Exposure	Spectrum Observed
7	-0.60	18 hr	tetragonal PbO
	-0.10	3 hr	tetragonal PbO
	+0.60	18 hr	tetragonal PbO
	+1.10	17 hr	buffer
10	-0.76	17 hr	tetragonal PbO
	-0.27	45 min	tetragonal PbO
	-0.27	18 hr	tetragonal PbO
	+0.24	17 hr	tetragonal PbO
	+0.46	22 hr	tetragonal PbO
	+0.51	17 hr	tetragonal PbO
	+0.90	18 hr	buffer

* Phosphate buffer used for pH7 solution, carbonate buffer used for pH10 solution.

REFERENCES

1. M. Hair, "Infrared Spectroscopy in Surface Chemistry", Marcel Dekker, New York, 1967.
2. R.J. Thibau, C.W. Brown and R.H. Heidersbach, "Raman Spectroscopy of Passive Films Formed on Lead in Acid Environments", Paper No. 23, Corrosion/77, San Francisco, March, 1977.
3. E.S. Reid, R.P. Cooney, P.J. Hendra and M. Fleischmann, Journal of Electro-analytical Chemistry, 80 (1977) 405.
4. R.W. Hannah, Applied Spectroscopy, 17 (1963), 23.
5. K. Nakamoto, "Infrared Spectra of Inorganic and Coordination Compounds", Wiley-Interscience, New York, 1970.
6. R.G. Greenler, Journal of Chemical Physics, 50 (1969), 1963.
7. H.G. Tompkins, Applied Spectroscopy, 30 (1976), 377.
8. T. Evans, Corrosion Science, 17 (1977), 105.
9. S. Shimodaira, Proceedings, Passivity and Its Breakdown on Iron and Iron Base Alloys, USA-Japan Seminar, R.W. Staehle and H. Okada, eds., NACE, Houston, 1976.
10. H. Ebiko and W. Suetaka, Corrosion Science, 19 (1970), 111.
11. N.D. Greene, "Experimental Electrode Kinetics", RPI, Troy, N.Y., 1965.
12. M. Pourbaix, "Atlas of Electrochemical Equilibria", NACE, Houston, 1969.
13. M. McDevitt and W. Baun, Spectrochimica Acta, 20 (1964), 799.
14. J.D. Donaldson, M.T. Donoghue, and S.D. Ross, Spectrochimica Acta, 30A (1974), 1967.
15. G.W. Poling, Journal of the Electrochemical Society, 116 (1969), 958.

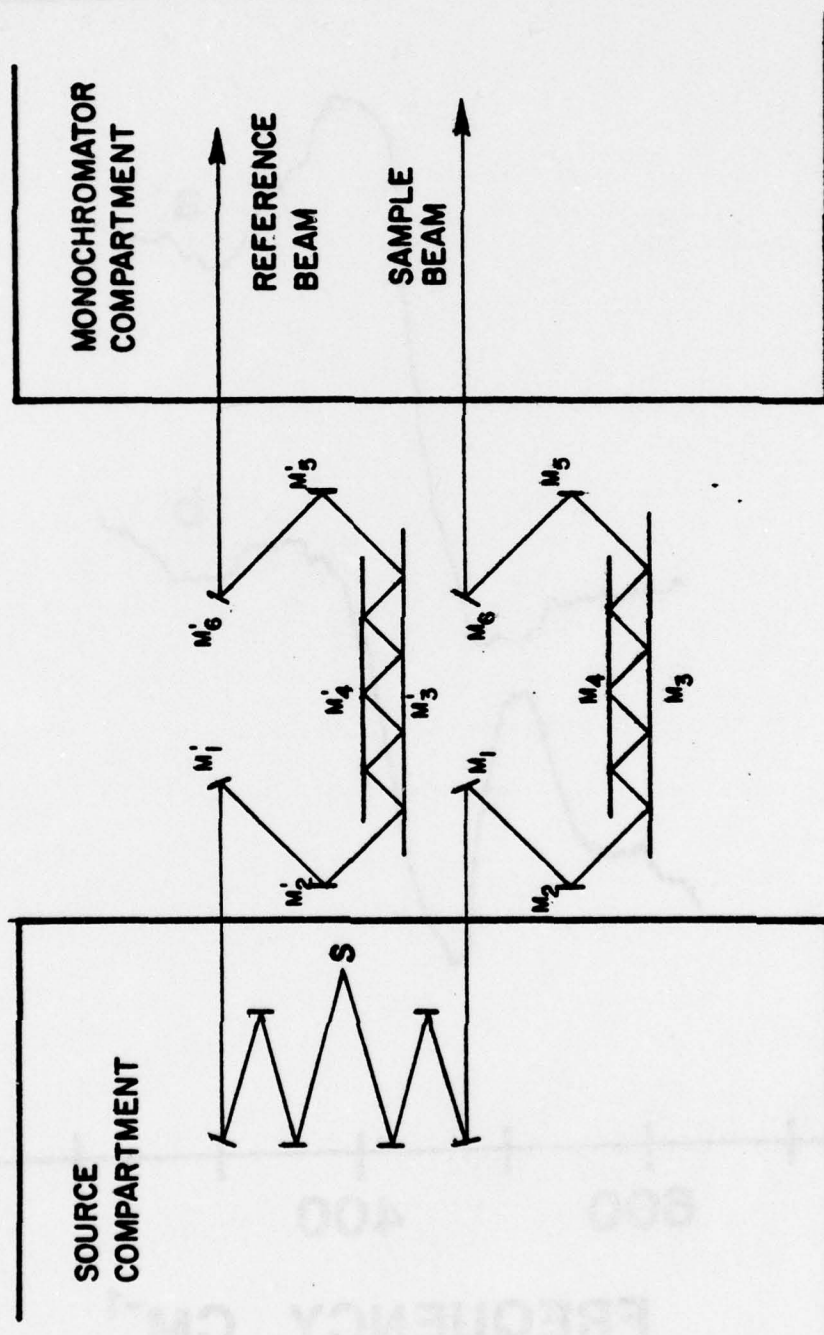
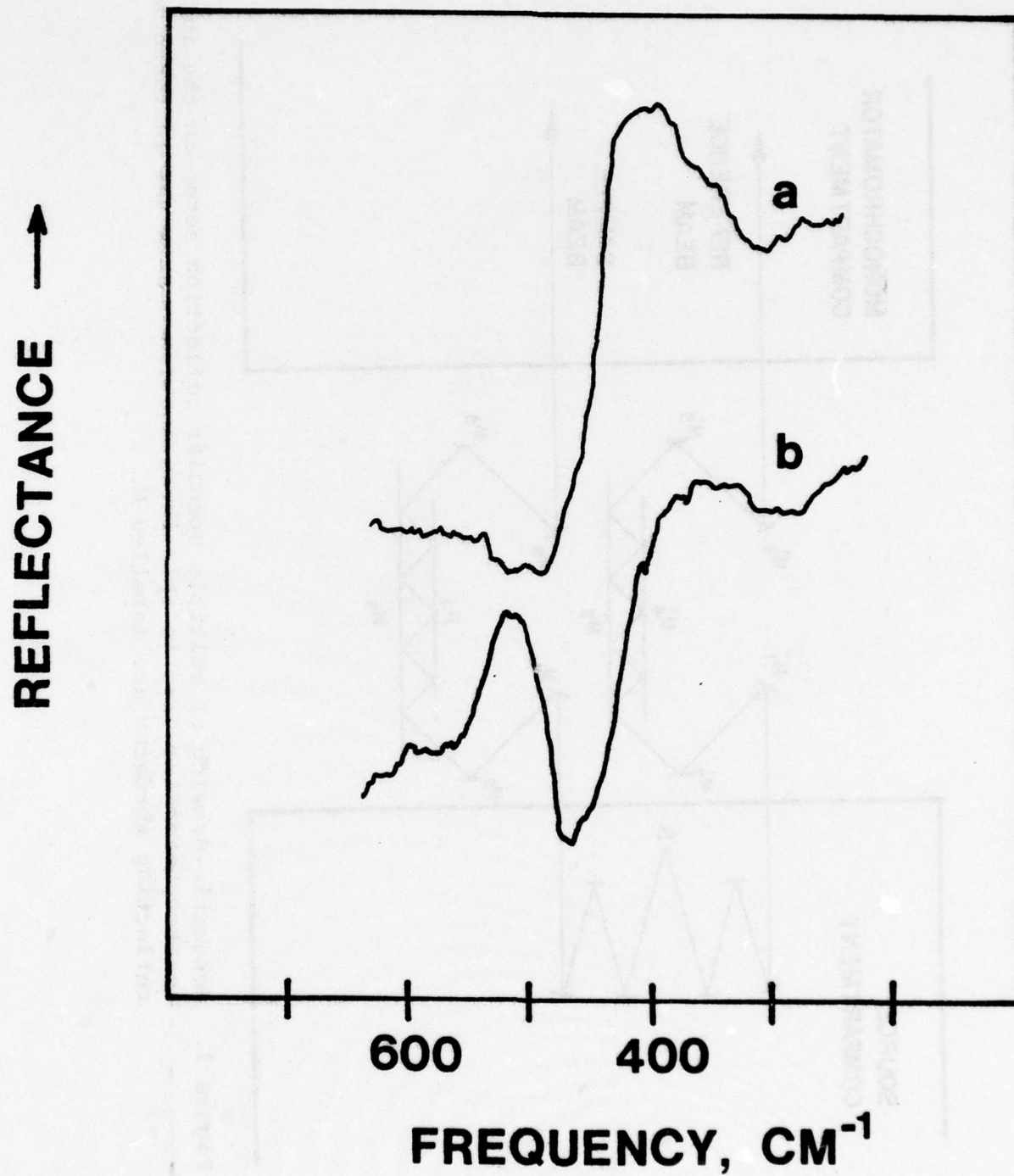


Figure 1. Schematic drawing of multiple specular reflection setup in the infrared spectrophotometer used in this investigation. S is the infrared source, reflecting surfaces are labelled M.

Figure 2. (a) Infrared reflection-absorption spectrum of a lead surface after 17 hour exposure in pH 10 solution at +0.24v (vs. SHE), (b) the same surface with a different setting of the polarizer



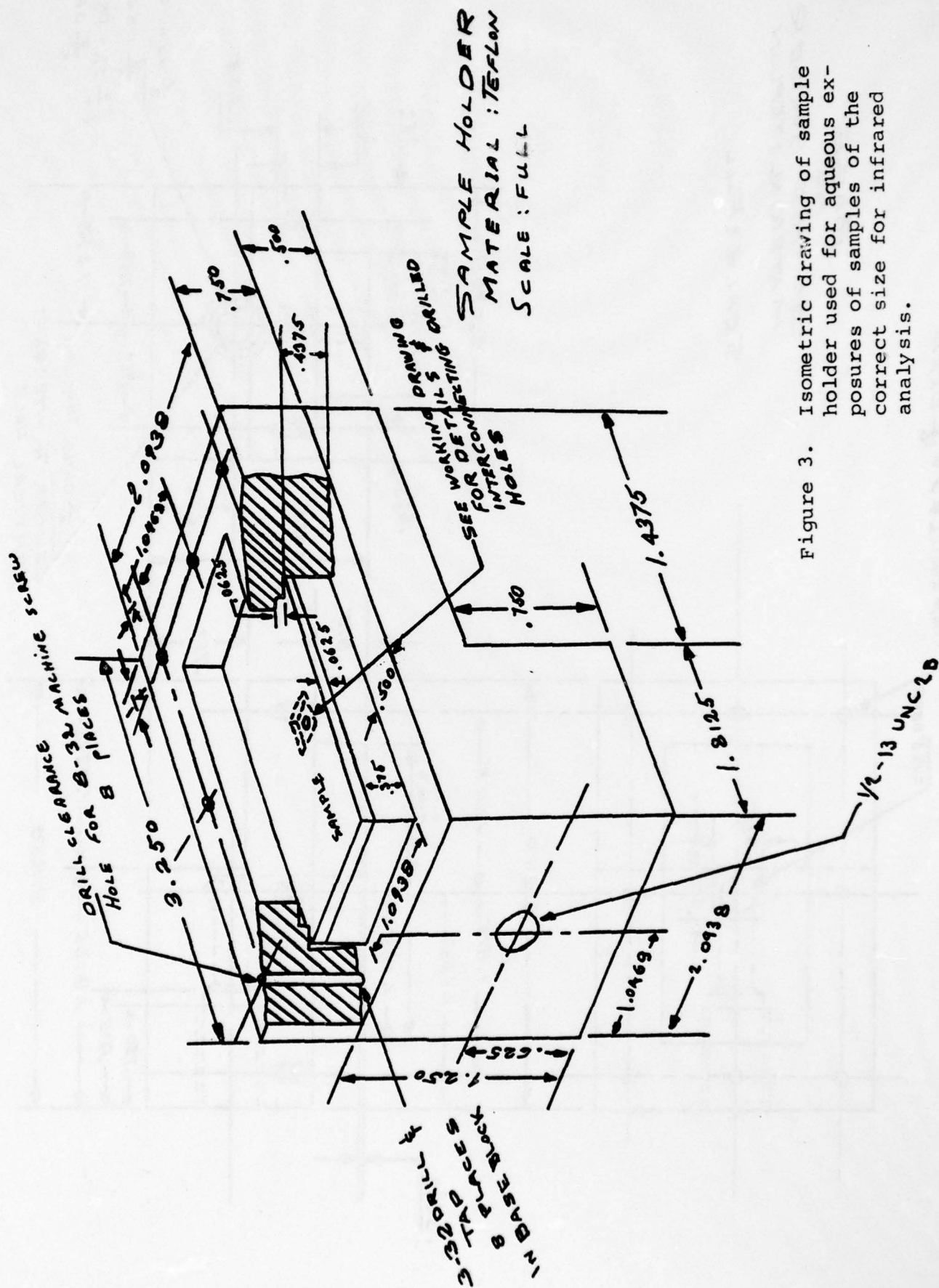


Figure 4. Base for sample holder

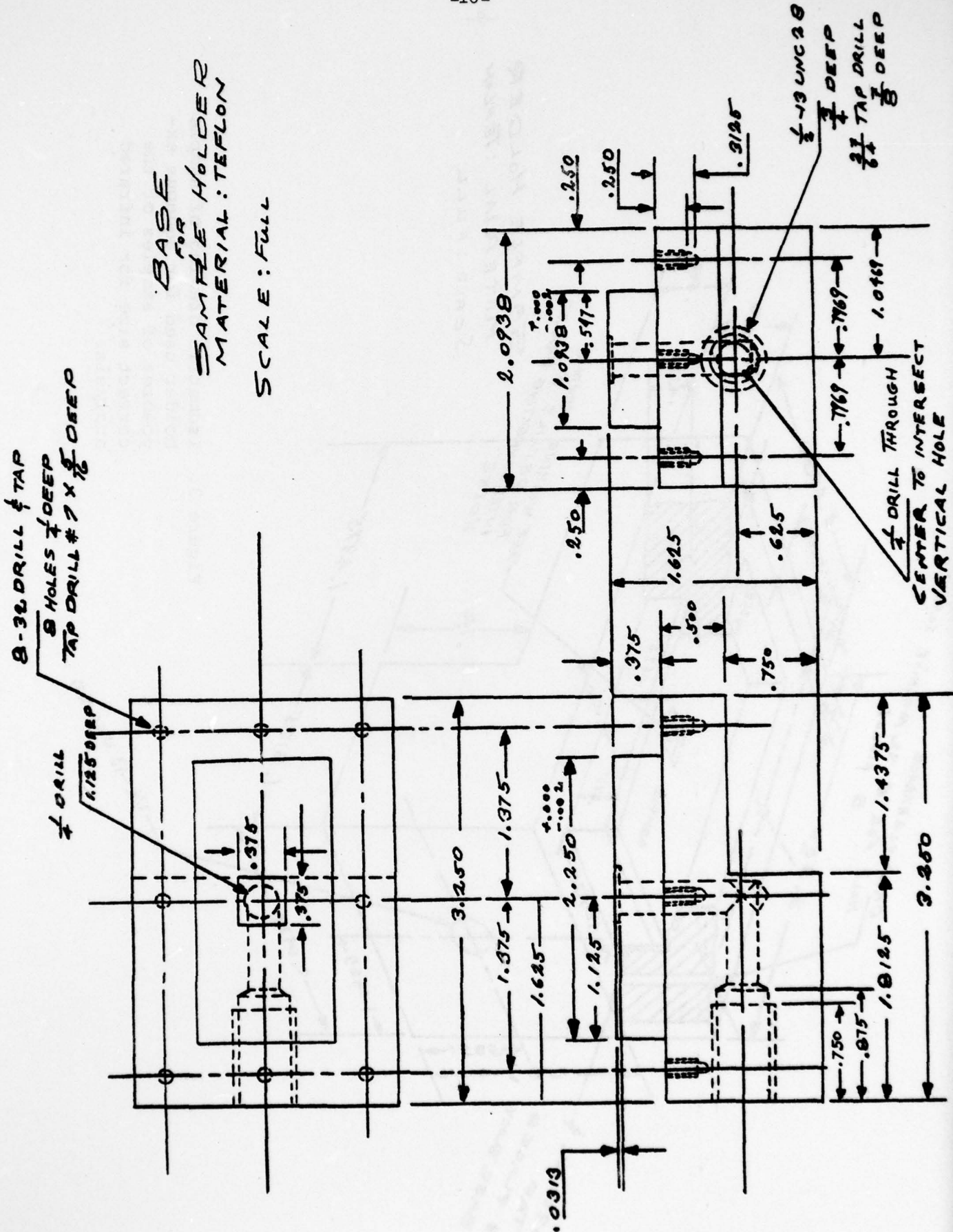
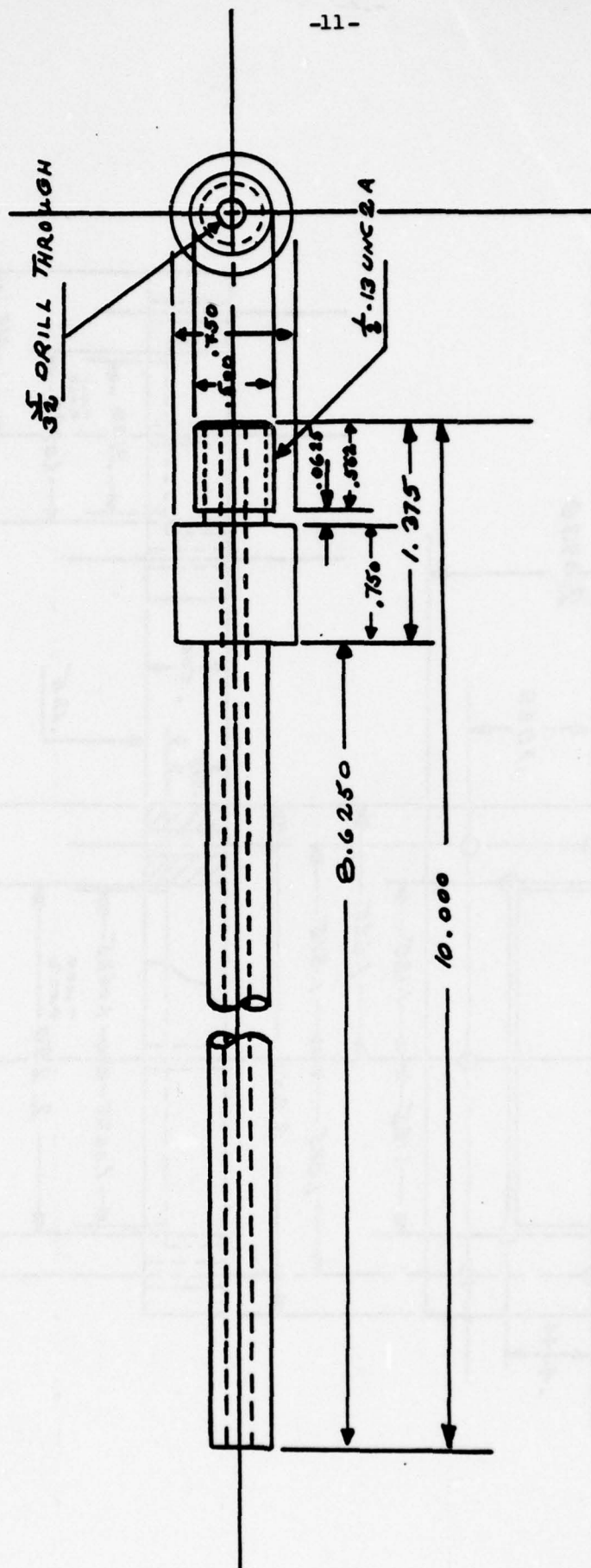


Figure 5. Support tube for sample holder



SAMPLE HOLDER TUBE
MATERIAL: TEFLON

SCALE: FULL

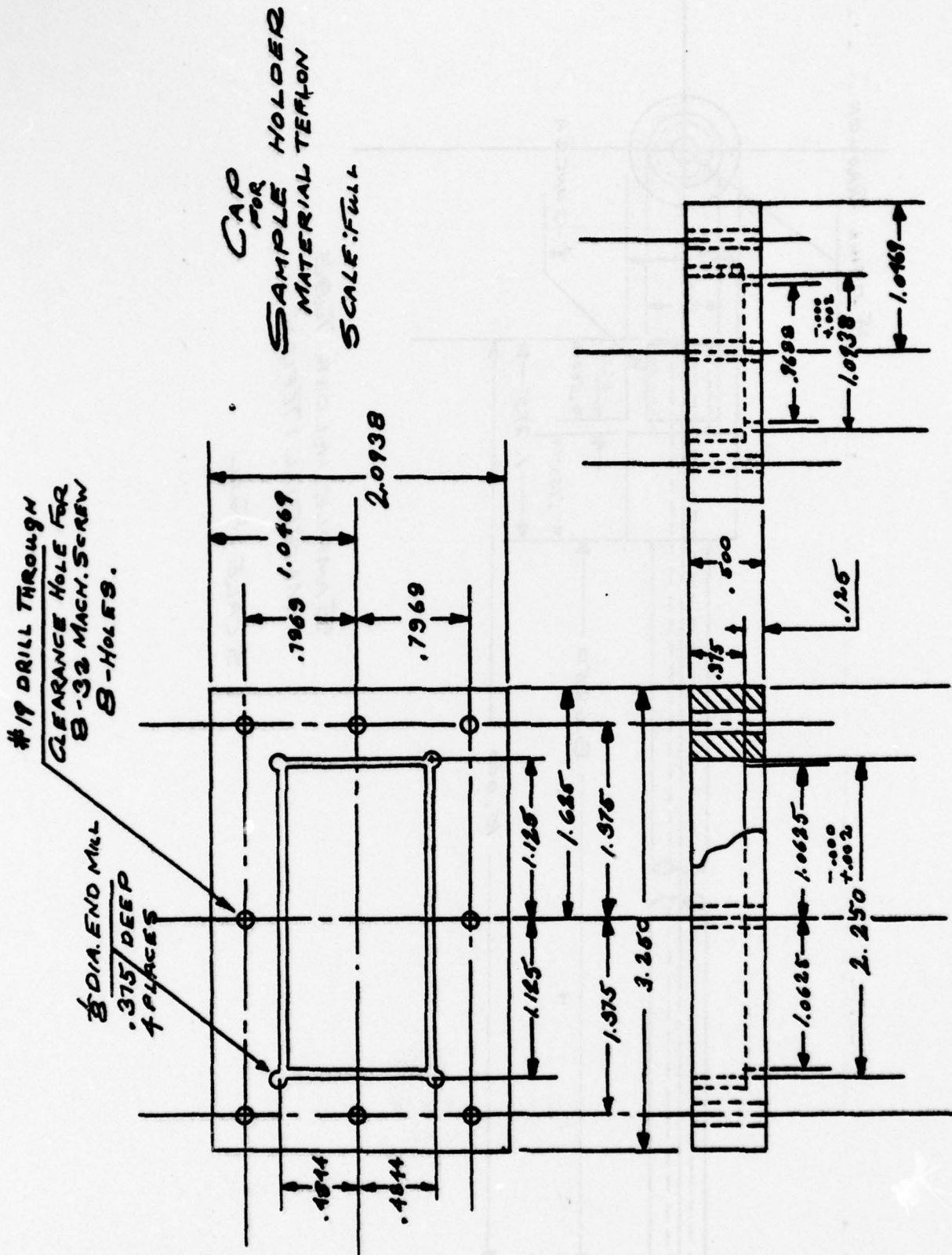
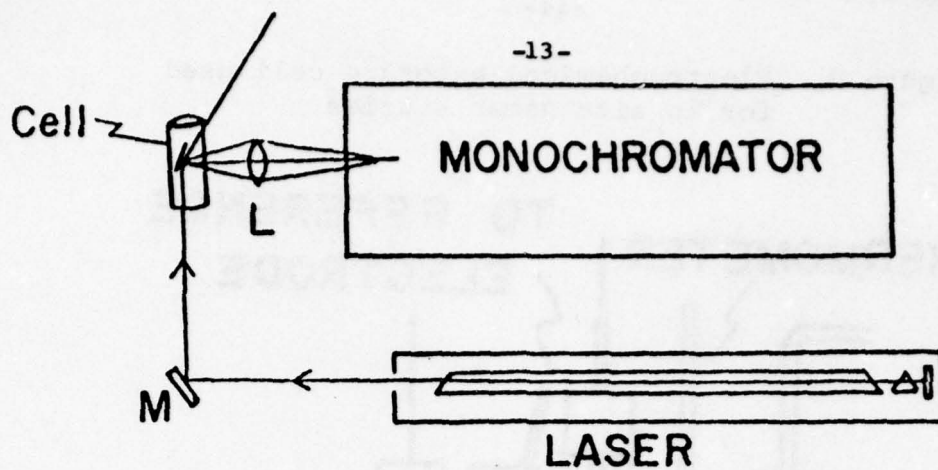
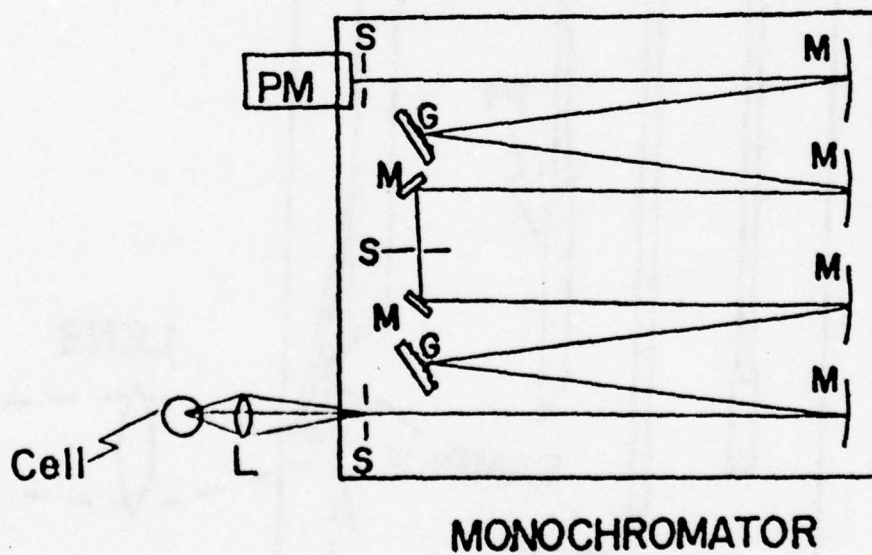


Figure 6. Sample holder cap



SIDE VIEW



TOP VIEW

Figure 7. Optical schematic of Raman spectrometer

Figure 8. Electrochemical exposure cell used for in situ Raman studies

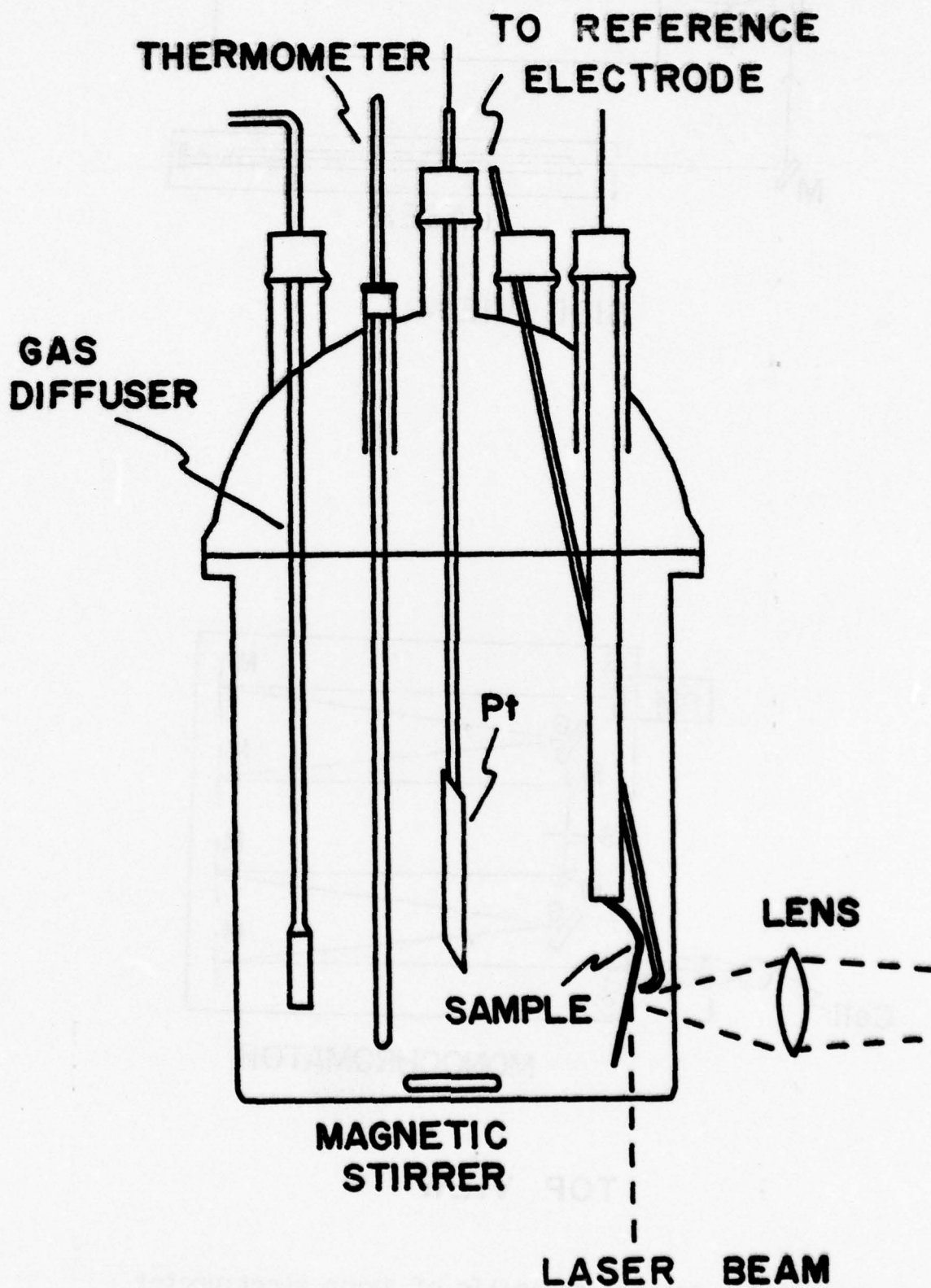


Figure 9. (a) In situ Raman spectrum of tetragonal PbO film formed on a lead surface after 2 hours at -0.60v (vs. SHE) in pH 7 buffer solution, (b) Raman spectrum of the same sample after completion of 3-1/2 hours of exposure and 30 minutes drying at room temperature

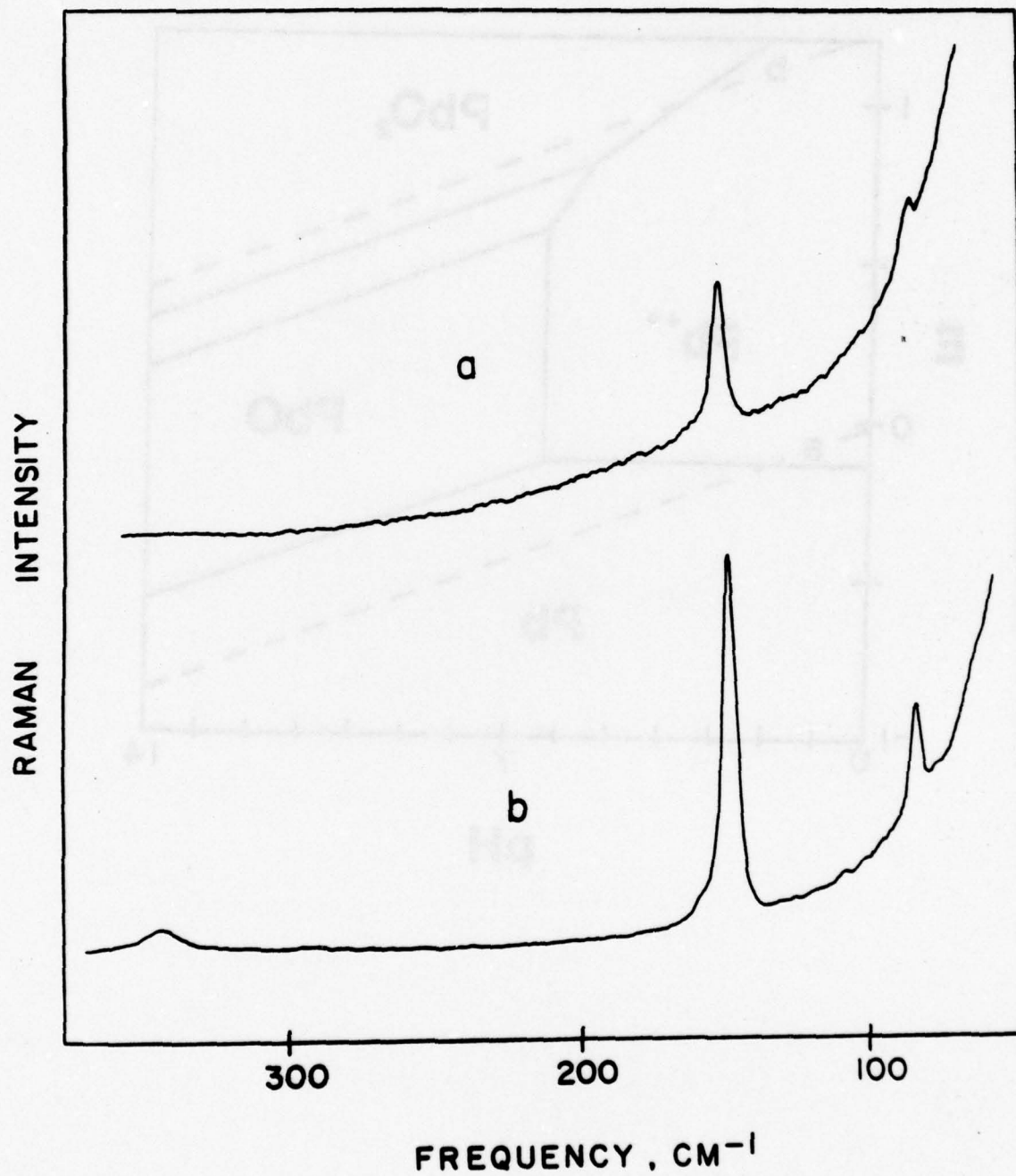


Figure 10. Simplified potential-pH (Pourbaix) diagram for lead in water, assuming no anion effects (Reference 12)

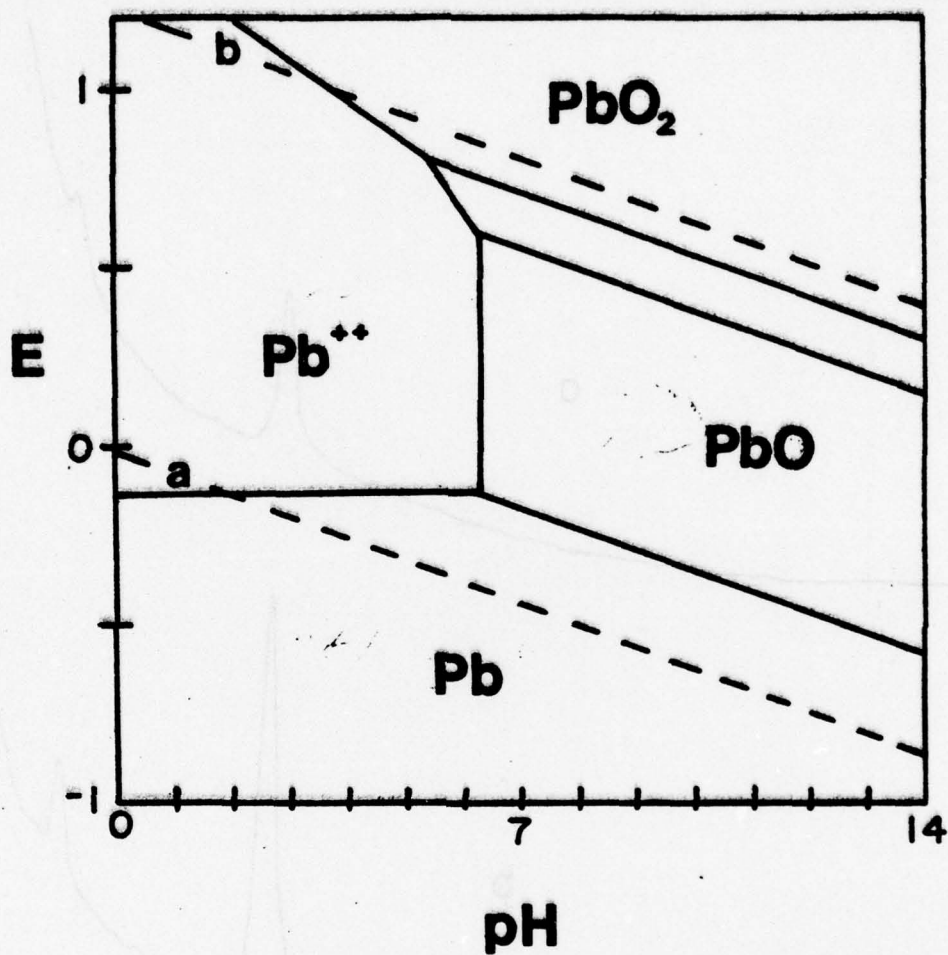


Figure 11. Infrared spectrum of orthorhombic PbO surface film on lead metal. The sample was exposed to 0.1M chloride, pH 7 buffer solution at +0.59v (vs. SHE) for 17 hours.

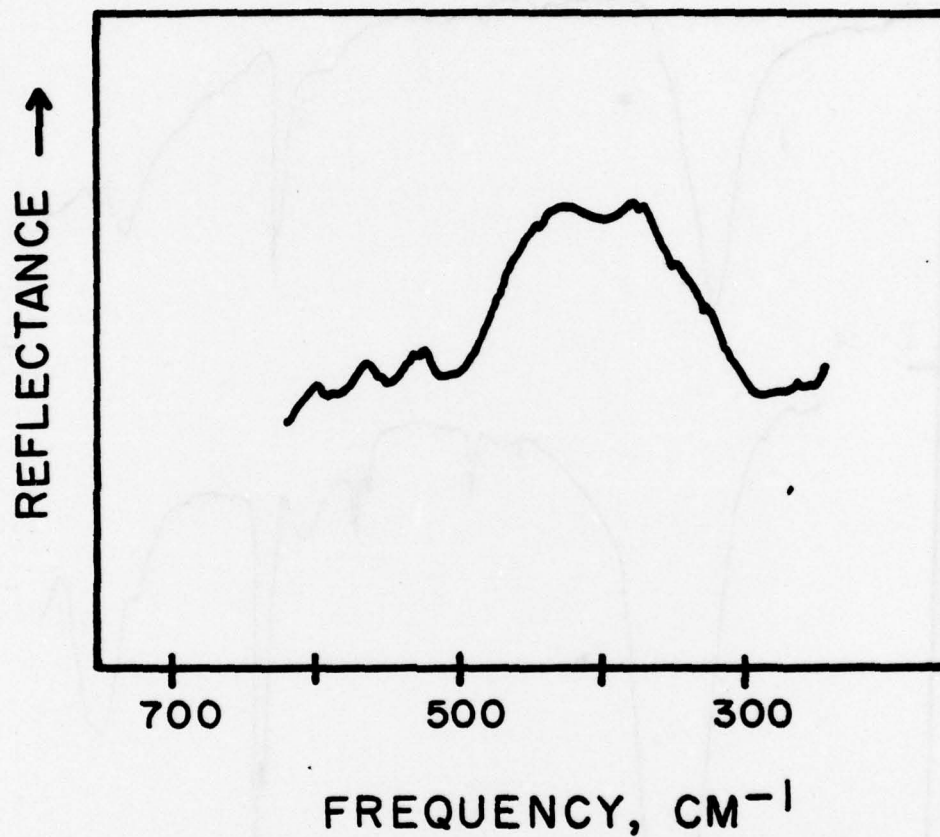


Figure 12. Infrared spectra of basic lead carbonate (a) film on lead which had been exposed 18 hours at +0.90v (vs. SHE) in pH 10 carbonate buffer, (b) reagent grade $(\text{PbCO}_3)_2 \cdot \text{Pb}(\text{OH})_2$ in KBr pellet

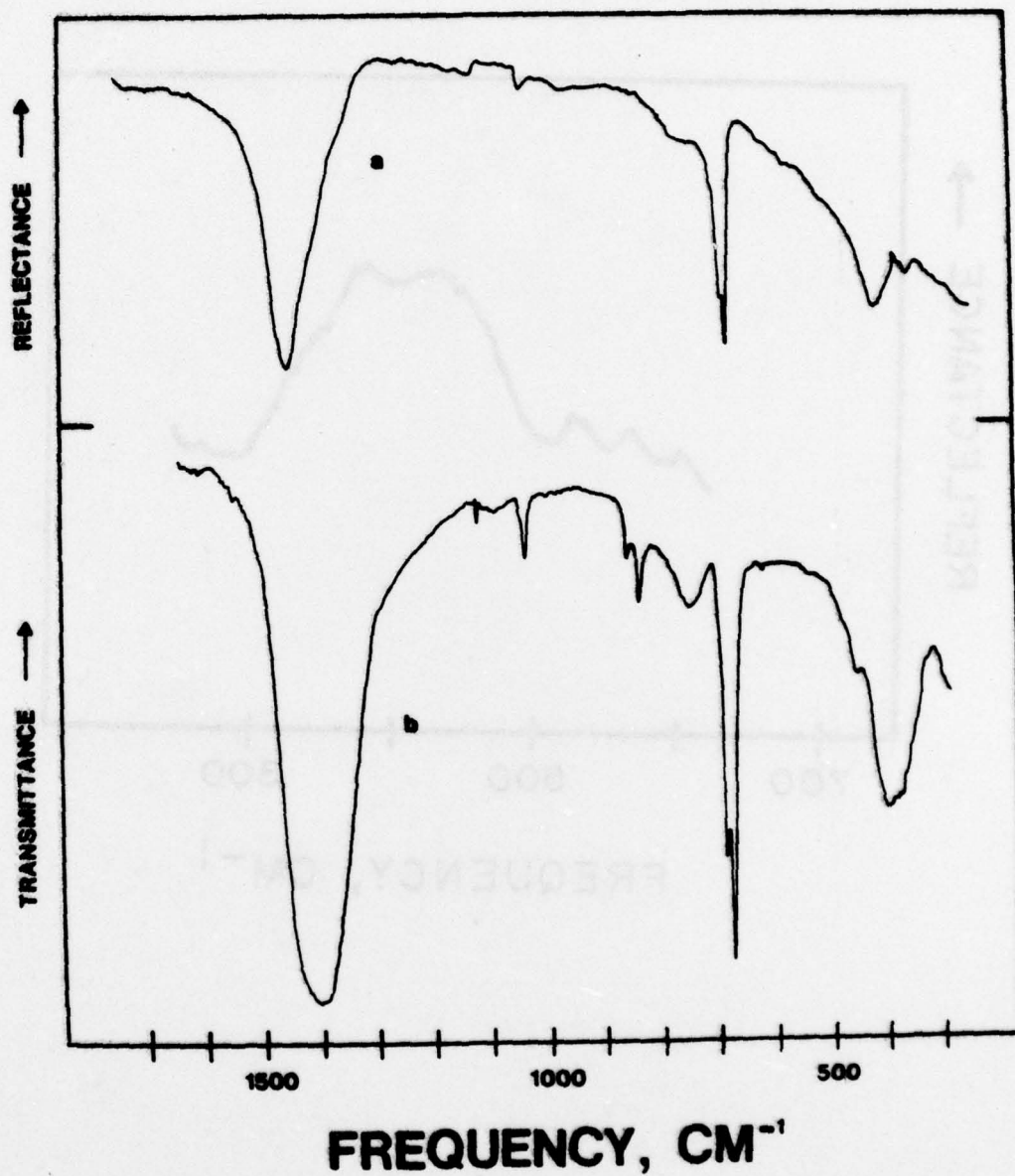


Figure 13. Raman spectrum of Pb_3O_4

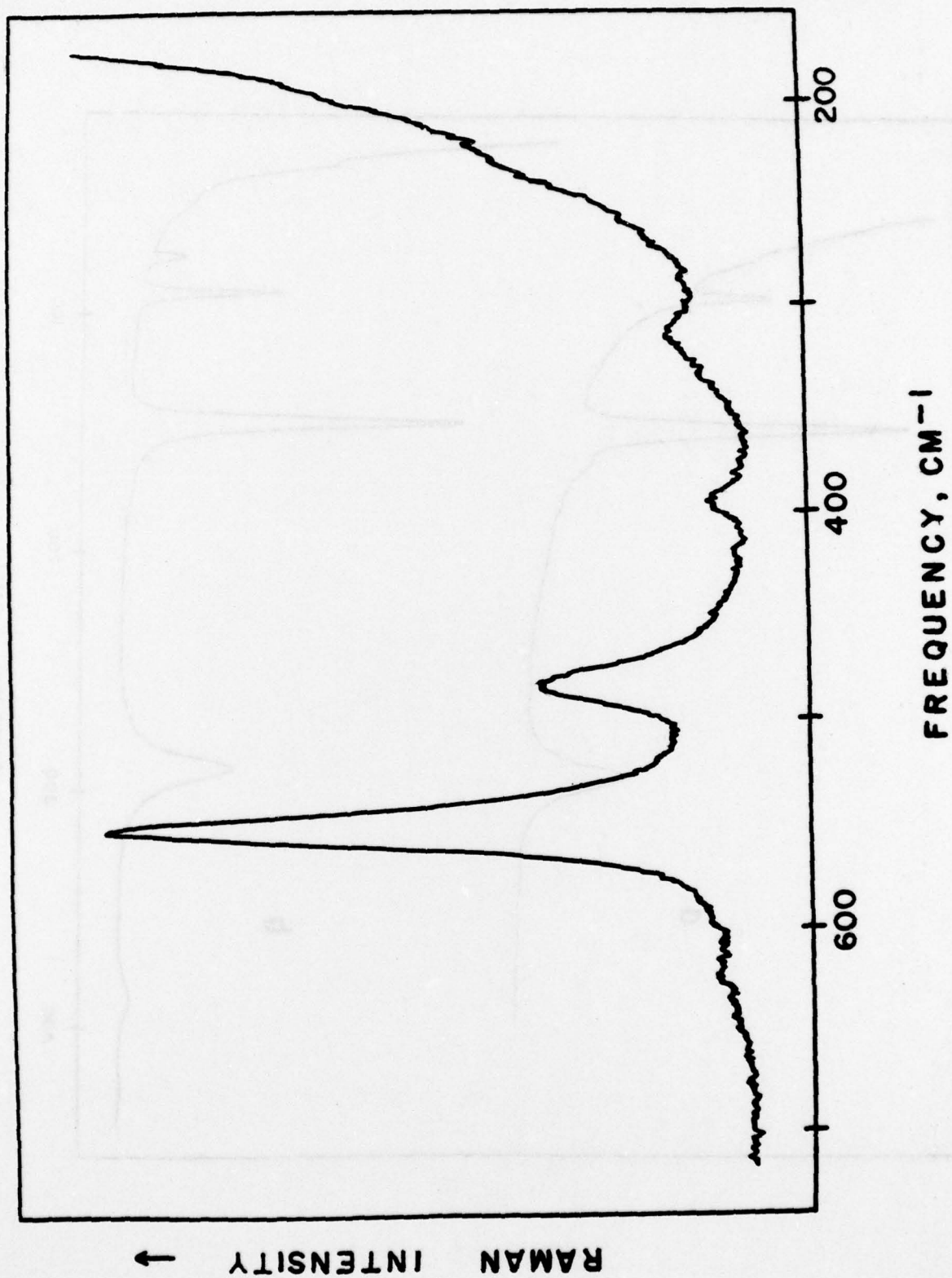


Figure 14. Raman spectra of (a) orthorhombic PbO film formed by 18 hour exposure of lead at +0.59v (vs. SHE) in 0.1M chloride, pH 7 solution, (b) orthorhombic PbO powder

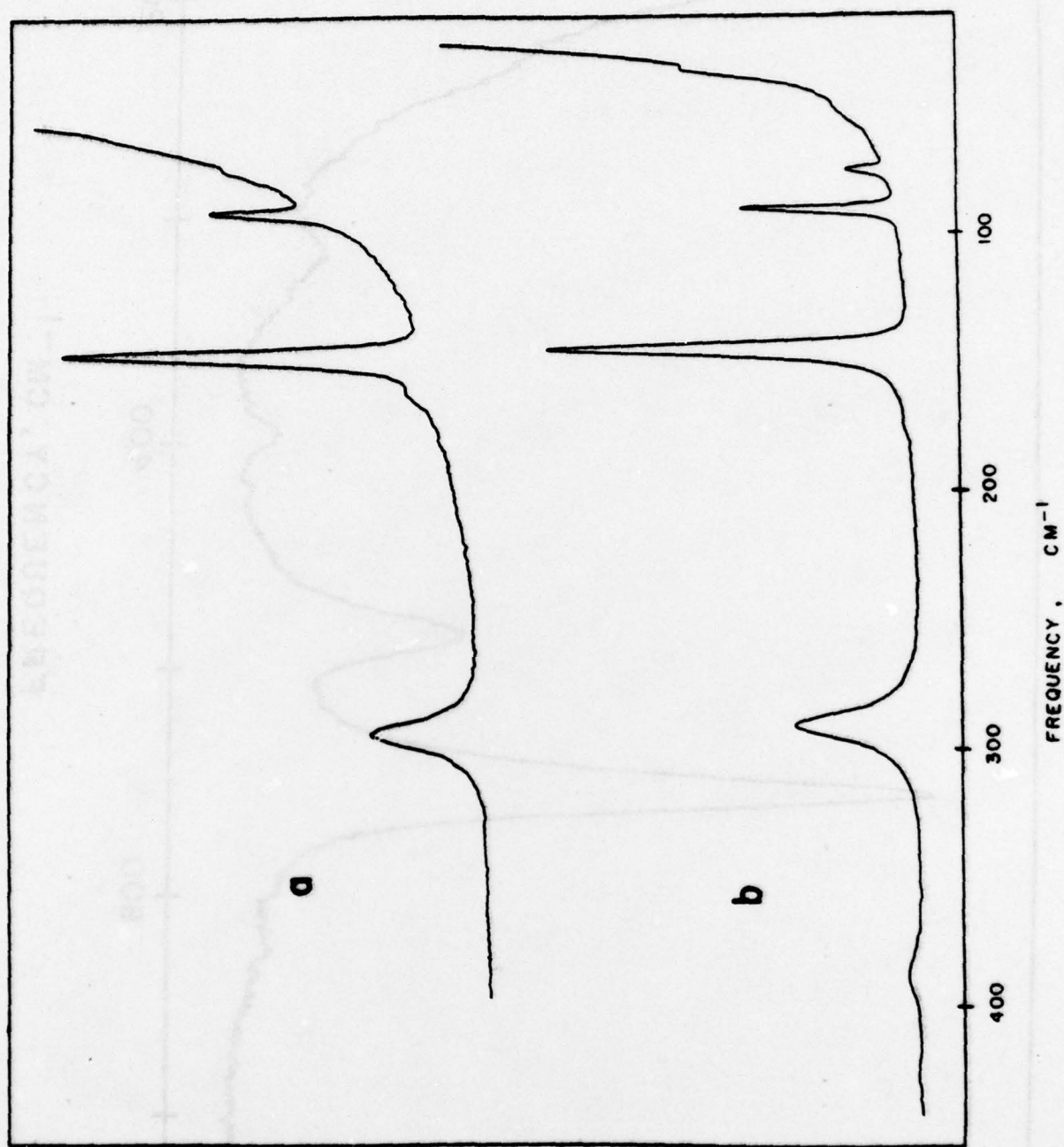


Figure 15. Potential-pH (Pourbaix) diagram calculated for lead in aqueous solution assuming no anion effects. Thermodynamic data used for the calculations were supplied by the Thermodynamics Data Center, National Bureau of Standards. Experimental points represented by o indicate tetragonal PbO was found, w indicates α -PbO₂.

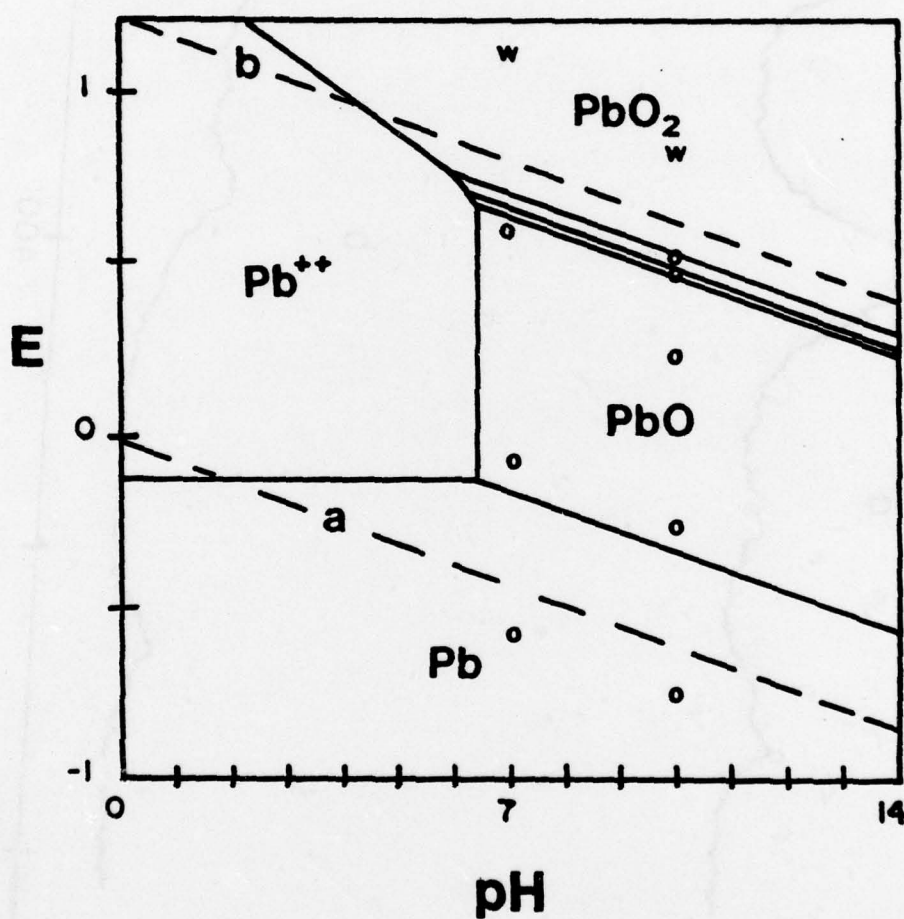


Figure 16. Raman spectra of (a) α -FeOOH, and (b) γ -FeOOH

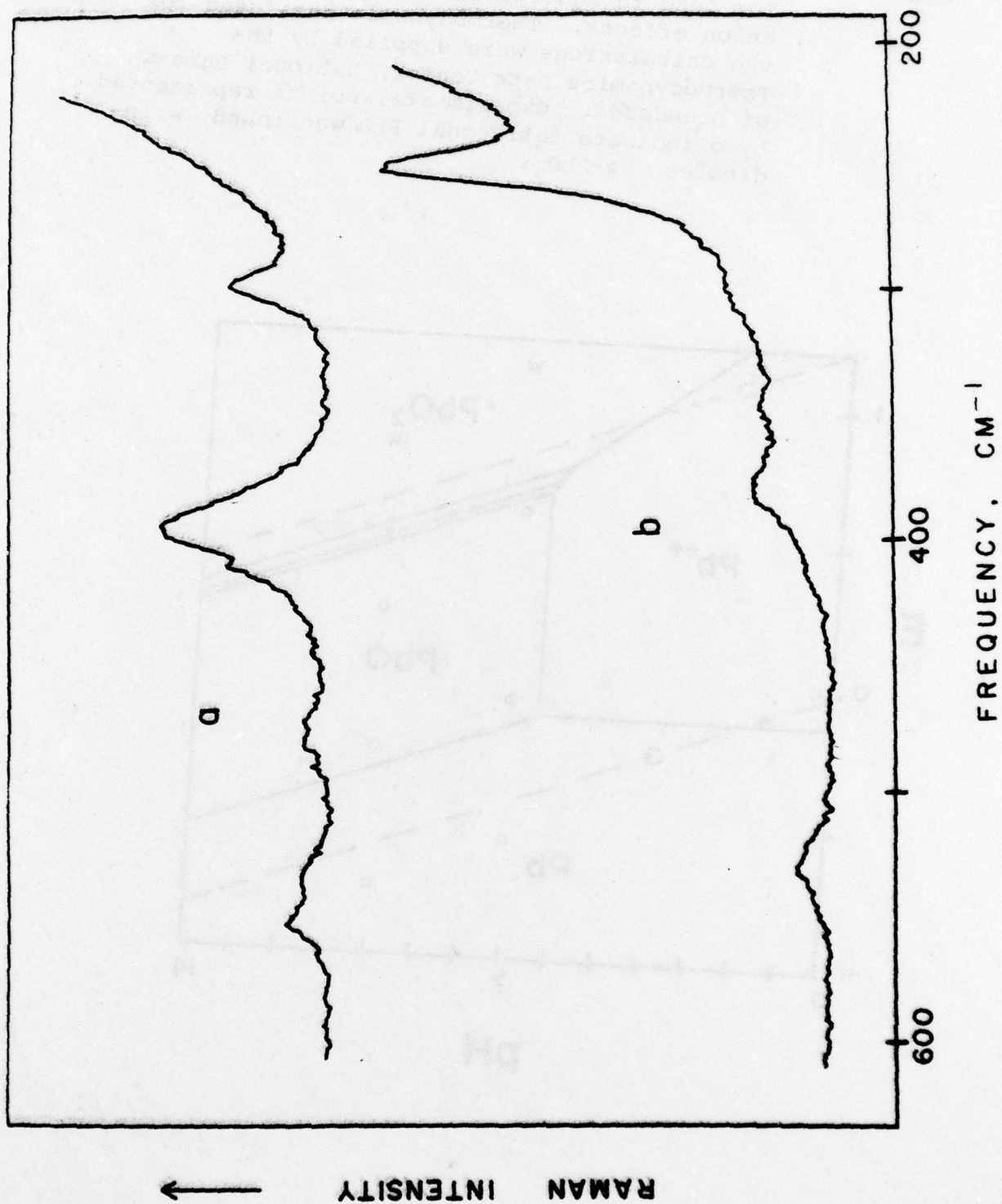


Figure 17. Raman spectra of (a) α -Fe₂O₃, and (b) γ -Fe₂O₃

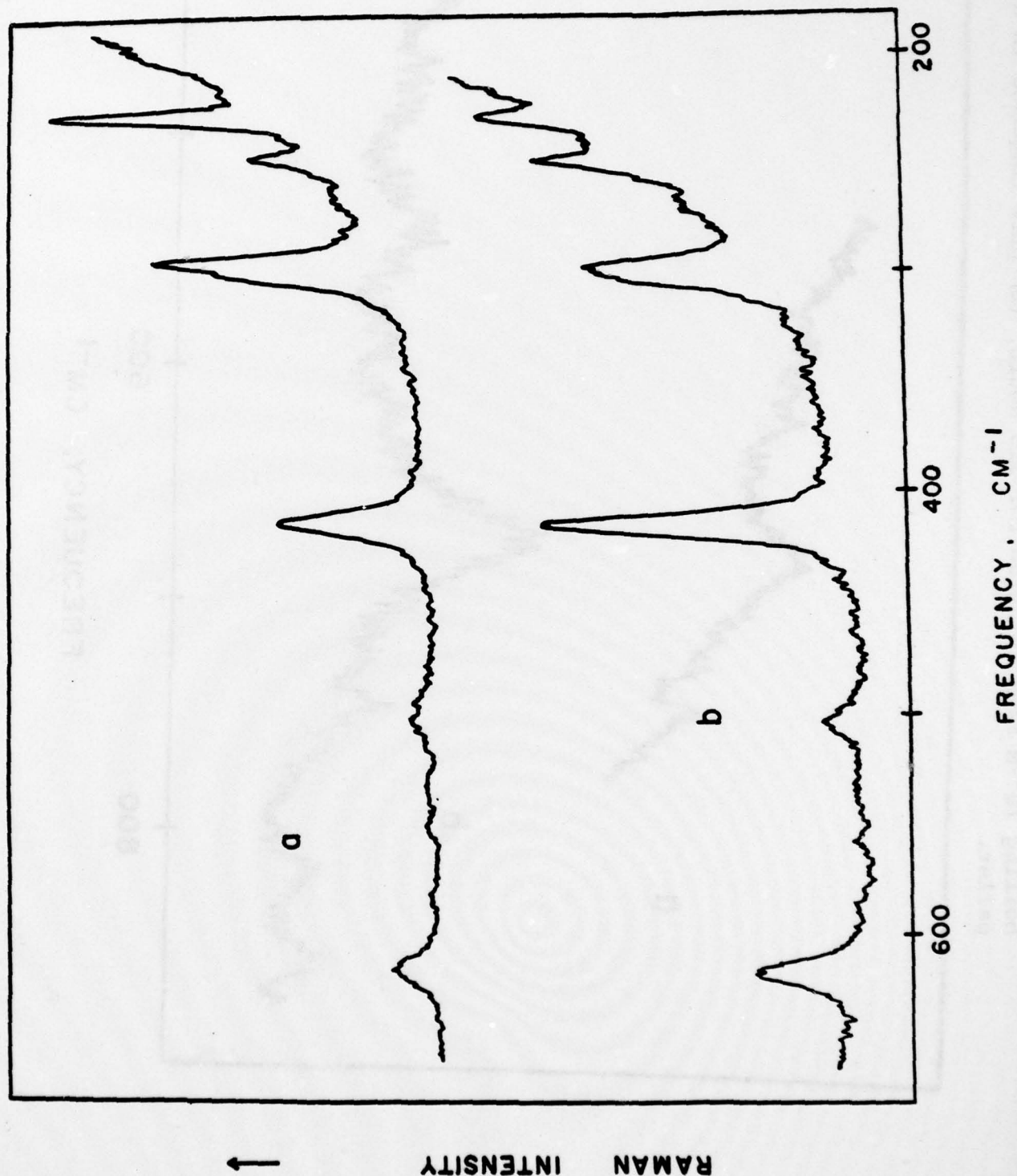


Figure 18. Raman spectra of Fe_3O_4 : (a) surface of Armco iron which had been in boiling 10-5M NaOH solution for 115 hours, (b) pure compound in a KBr pellet.

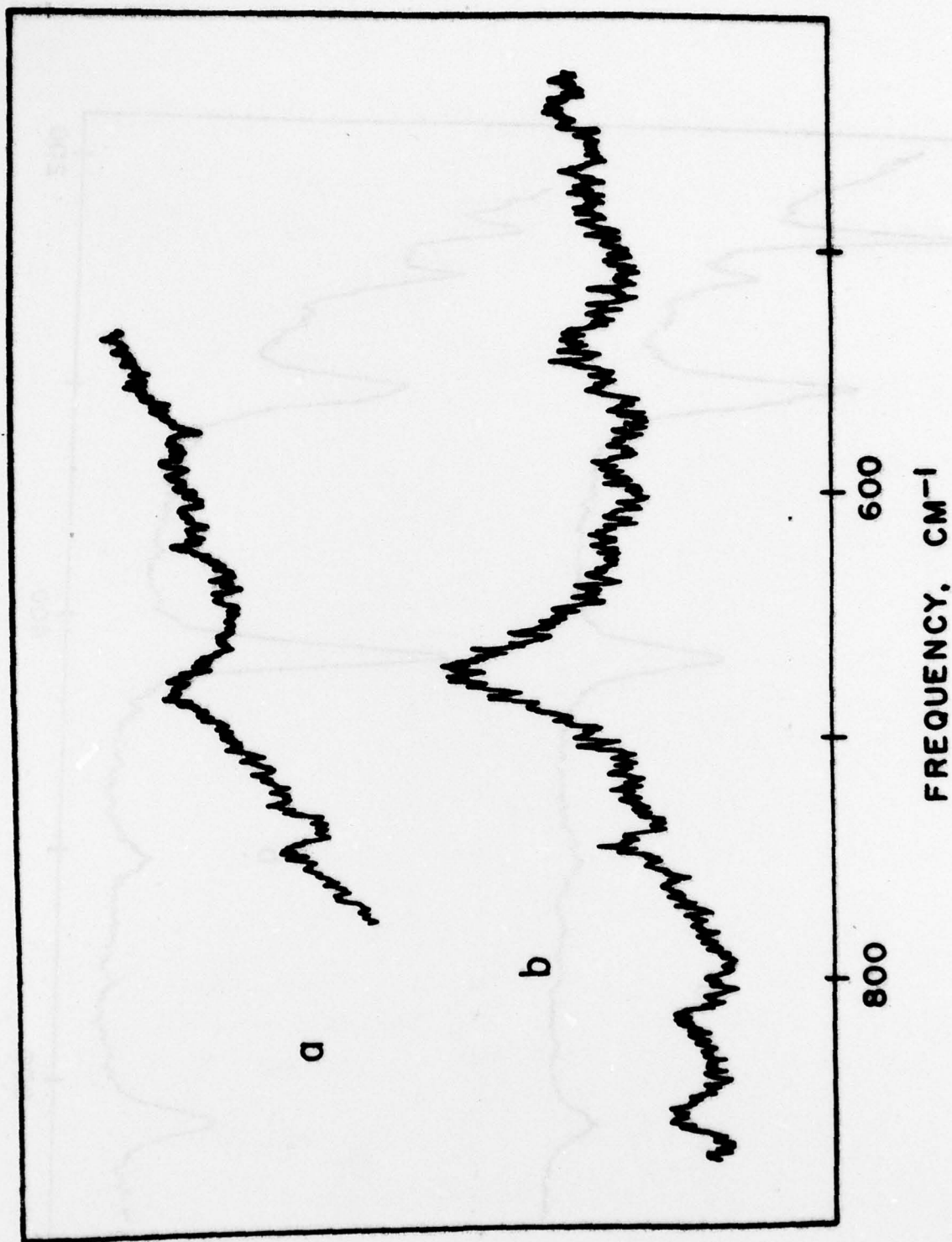
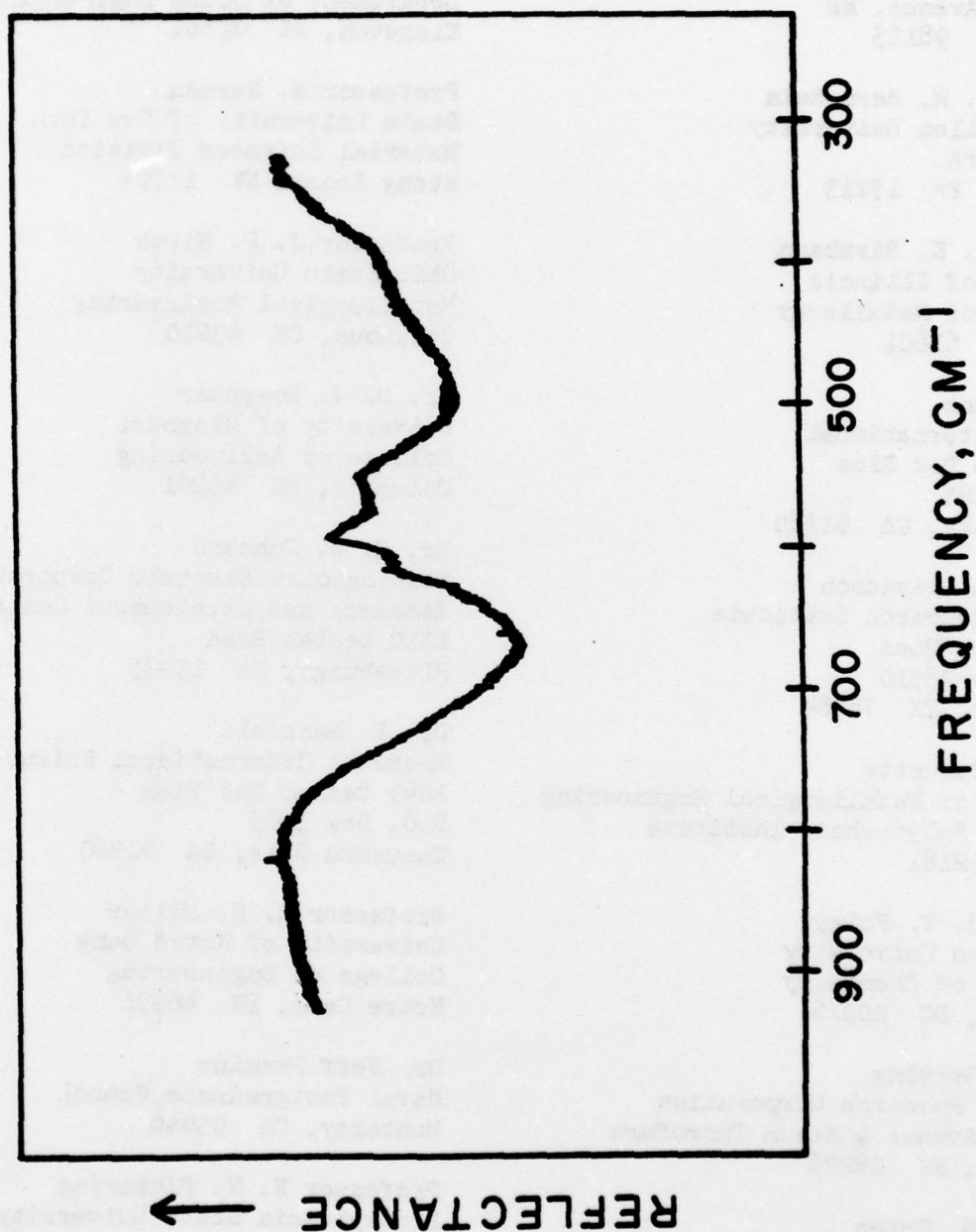


Figure 19. Infrared spectrum of mixed oxide coating formed on Armco iron by air oxidation at 220°C.



C
July 1977

SUPPLEMENTARY DISTRIBUTION LIST

Technical and Summary Reports

Dr. T. R. Beck
Electrochemical Technology Corporation
10035 31st Avenue, NE
Seattle, WA 98125

Professor I. M. Bernstein
Carnegie-Mellon University
Schenley Park
Pittsburgh, PA 15213

Professor H. K. Birnbaum
University of Illinois
Department of Metallurgy
Urbana, IL 61801

Dr. Otto Buck
Rockwell International
1049 Camino Dos Rios
P.O. Box 1085
Thousand Oaks, CA 91360

Dr. David L. Davidson
Southwest Research Institute
8500 Culebra Road
P.O. Drawer 28510
San Antonio, TX 78284

Dr. D. J. Duquette
Department of Metallurgical Engineering
Rensselaer Polytechnic Institute
Troy, NY 12181

Professor R. T. Foley
The American University
Department of Chemistry
Washington, DC 20016

Mr. G. A. Gehring
Ocean City Research Corporation
Tennessee Avenue & Beach Thorofare
Ocean City, NJ 08226

Dr. J. A. S. Green
Martin Marietta Corporation
1450 South Rolling Road
Baltimore, MD 21227

Professor R. H. Heidersbach
University of Rhode Island
Department of Ocean Engineering
Kingston, RI 02881

Professor H. Herman
State University of New York
Material Sciences Division
Stony Brook, NY 11794

Professor J. P. Hirth
Ohio State University
Metallurgical Engineering
Columbus, OH 43210

Dr. D. W. Hoepfner
University of Missouri
College of Engineering
Columbia, MO 65201

Dr. E. W. Johnson
Westinghouse Electric Corporation
Research and Development Center
1310 Beulah Road
Pittsburgh, PA 15235

Dr. F. Mansfeld
Rockwell International Science Center
1049 Camino Dos Rios
P.O. Box 1085
Thousand Oaks, CA 91360

Professor A. E. Miller
University of Notre Dame
College of Engineering
Notre Dame, IN 46556

Dr. Jeff Perkins
Naval Postgraduate School
Monterey, CA 93940

Professor H. W. Pickering
Pennsylvania State University
Department of Material Sciences
University Park, PA 16802

C
July 1977

SUPPLEMENTARY DISTRIBUTION LIST
(Continued)

Dr. William R. Prindle
National Academy of Sciences
National Research Council
2101 Constitution Avenue
Washington, DC 20418

Professor R. W. Staehle
Ohio State University
Department of Metallurgical Engineering
Columbus, OH 43210

Dr. Barry C. Syrett
Stanford Research Institute
333 Ravenswood Avenue
Menlo Park, CA 94025

Dr. R. P. Wei
Lehigh University
Institute for Fracture and
Solid Mechanics
Bethlehem, PA 18015

Professor H. G. F. Wilsdorf
University of Virginia
Department of Materials Science
Charlottesville, VA 22903

BASIC DISTRIBUTION LIST (Cont'd)

October 1976

<u>Organization</u>	<u>No. of Copies</u>	<u>Organization</u>	<u>No. of Copies</u>
Naval Sea System Command Washington, D.C. 20362 Attn: Code 035	(1)	NASA Headquarters Washington, D.C. 20546 Attn: Code RRM	(1)
Naval Facilities Engineering Command Alexandria, Virginia 22331 Attn: Code 03	(1)	NASA Lewis Research Center 21000 Brookpark Road Cleveland, Ohio 44135 Attn: Library	(1)
Scientific Advisor Commandant of the Marine Corps Washington, D.C. 20380 Attn: Code AX	(1)	National Bureau of Standards Washington, D.C. 20234 Attn: Metallurgy Division (1) Inorganic Materials Division (1)	
Naval Ship Engineering Center Department of the Navy CTR BG #2 3700 East-West Highway Prince Georges Plaza Hyattsville, Maryland 20782 Attn: Engineering Materials and Services Office, Code 6101	(1)	Defense Metals and Ceramics Information Center Battelle Memorial Institute 505 King Avenue Columbus, Ohio 43201	(1)
Army Research Office Box CM, Duke Station Durham, North Carolina 27706 Attn: Metallurgy & Ceramics Div.	(1)	Director Ordnance Research Laboratory P.O. Box 30 State College, Pennsylvania 16801	(1)
Army Materials and Mechanics Research Center Watertown, Massachusetts 02172 Attn: Res. Programs Office (ANCOMR-P)	(1)	Director Applied Physics Laboratory University of Washington 1013 Northeast Fortieth Street Seattle, Washington 98105	(1)
Air Force Office of Scientific Research Bldg. 410 Bolling Air Force Base Washington, D.C. 20332 Attn: Chemical Science Directorate (1) Electronics and Solid State Sciences Directorate (1)		Metals and Ceramics Division Oak Ridge National Laboratory P.O. Box X Oak Ridge, Tennessee 37380	(1)
Air Force Materials Lab (LA) Wright-Patterson AFB Dayton, Ohio 45433	(1)	Los Alamos Scientific Laboratory P.O. Box 1663 Los Alamos, New Mexico 87544 Attn: Report Librarian	(1)
		Argonne National Laboratory Metallurgy Division P.O. Box 229 Lemont, Illinois 60439	(1)

BASIC DISTRIBUTION LIST

October 1976

Technical and Summary Reports		
<u>Organization</u>	<u>No. of Copies</u>	<u>Organization</u>
Defense Documentation Center Cameron Station Alexandria, Virginia 22314	(12)	Naval Construction Battalion Civil Engineering Laboratory Port Hueneme, California 93043 Attn: Materials Division
Office of Naval Research Department of the Navy		Naval Electronics Laboratory Center San Diego, California 92152 Attn: Electron Materials Sciences Division
Attn: Code 471	(1)	
Code 102	(1)	
Code 470	(1)	
Commanding Officer Office of Naval Research Branch Office 495 Summer Street Boston, Massachusetts 02210	(1)	Naval Missile Center Materials Consultant Code 3312-1 Point Mugu, California 93041
Commanding Officer Office of Naval Research Branch Office 536 South Clark Street Chicago, Illinois 60605	(1)	Commanding Officer Naval Surface Weapons Center White Oak Laboratory Silver Spring, Maryland 20910 Attn: Library
Office of Naval Research San Francisco Area Office 760 Market Street, Room 447 San Francisco, California 94102 Attn: Dr. P. A. Miller	(1)	David W. Taylor Naval Ship R&D Center Materials Department Annapolis, Maryland 21402
Naval Research Laboratory Washington, D.C. 20390		Naval Undersea Center San Diego, California 92132 Attn: Library
Attn: Code 6000	(1)	
Code 6100	(1)	
Code 6300	(1)	
Code 6400	(1)	
Code 2627	(1)	
Naval Air Development Center Code 302 Warminster, Pennsylvania 18974 Attn: Mr. F. S. Williams	(1)	Naval Underwater System Center Newport, Rhode Island 02840 Attn: Library
Naval Air Propulsion Test Center Trenton, New Jersey 08628 Attn: Library	(1)	Naval Weapons Center China Lake, California 93555 Attn: Library
		Naval Postgraduate School Monterey, California 93940 Attn: Mechanical Engineering Dept.
		Naval Air Systems Command Washington, D.C. 20360
		Attn: Code 52031
		Code 52032
		Code 320

BASIC DISTRIBUTION LIST (Cont'd)

October 1976

<u>Organization</u>	<u>No. of Copies</u>	<u>Organization</u>	<u>No. of Copies</u>
Brookhaven National Laboratory Technical Information Division Upton, Long Island New York 11973 Attn: Research Library	(1)		
Library Building 50 Room 134 Lawrence Radiation Laboratory Berkeley, California	(1)		